SEA LEVELS IN SOUTH AFRICA FROM BAROMETRIC OBSERVATIONS.

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The table for finding sea level altitudes from barometric observations which is this evening submitted to the Philosophical Society, though calculated according to the ordinary formula $\mu \log \frac{h_1}{h_2}$, is nevertheless empirical because the coefficient μ has not been determined according to theory, but has been assumed, as being 64,300, so as to give correct results in certain cases where these results are capable of independent verification.

The observations on which the table is based are those which have been taken at the Royal Observatory and at Kimberley. Other points where sufficient observations have been taken and where the results can be checked by railway levelling must be regarded as points of verification. Of these the principal are Aliwal North, Cradock, Graham's Town and Port Elizabeth. As the levels calculated by this table and those ascertained by telescopic spirit-levelling agree, within a few feet, the result must be regarded as satisfactory.

At present however the number of such points of verification is too small for thoroughly testing the table, which must therefore for the present be regarded as having only provisional value.

The table is not intended to be used to ascertain sea level from a few barometric observations, it can only be used when a continuous series of daily observations have been taken at a fixed hour.

When such observations have been taken for four or five years at any place, the sea level of that place ought to be deduced from the table with a probable error of less than 5 feet.

If only one year's continuous observations have been taken, the average for that year should be corrected for the average deviation that year from the general average over the Colony, and the result should still be correct within some 10 feet or so.

Even one month's continuous observations with a similar correction should give results sufficiently accurate to be of considerable practical value. As a justification for the abandonment of the theoretical formula in the construction of this table, it may be observed that this formula is based on certain hypothetical conditions which can seldom or never exist.

Thus it is assumed that the difference of pressure at two levels is due to the weight of the intermediate vertical column of air, whereas it is obvious that this will only be the case when the atmosphere is in equilibrium. If there is disturbance of equilibrium, whether of rest or motion, this will clearly affect the tension of the air. The error in this case enters principally in the correction for temperature. Temperatures registered by thermometers near the earth's surface are local and do not represent the temperature of the bulk of the superincumbent air stratum. Thus for example the mean of the temperatures registered by two thermometers, one, say at the Observatory and one on the top of Table Mountain, will not, except by mere accident, give the mean temperature of the stratum of air between these levels. This stratum, coming as it does over vast expanses of ocean, has attained a temperature which can be very little affected by radiation from a few miles of terrestrial surface, whereas the temperature registered by thermometers within a few feet of the surface must be greatly affected by such radiation.

When the points of observation are many miles apart, as for instance in the case of two thermometers, the one at Cape Town and the other at Kimberley, the ordinary correction for temperature at the time of observation is utterly fallacious. Whenever such observations have to be used, better results could probably be obtained by correcting for the mean temperature of the month. Barometric pressure, as is well known, does not in any way obey the daily changes of temperature. Temperature has generally but one maximum and one minimum in the twenty-four hours, while barometric pressure has two maxima and two minima. On the other hand variations of average monthly barometric pressure all seem connected with variations of average temperature.

It has been stated that what is at present required for meteorological purposes is not so much the collection of additional observations as the careful digestion of those which have been already accumulated. There are, no doubt, some good grounds for this observation, but the experience obtained in drawing up this table

rather goes to shew that while we have enough good material from which to draw useful deductions, we have on the other hand a superabundance of bad material from which it is impossible to deduce any satisfactory conclusions whatever. No one who has not made himself acquainted with the facts can realize the difficulty there is in getting a series of trustworthy observations taken under the same conditions at one place, extending over even four or five years.

What is still more unsatisfactory is that some of the fundamental data of meteorology are still undetermined. In drawing up this table, for example, it was necessary to ascertain as exactly as possible the average sea level barometric pressure round the South African coast. This is very imperfectly known. The estimates of sea level pressures at different latitudes, in the best works on meteorology, are very rough and imperfect, and as far as South Africa is concerned it may safely be said that it is only here in the neighbourhood of the Royal Observatory where careful observations have been made for almost fifty years that we have anything approaching accurate knowledge on this subject. Mr. Stone the former Astronomer-Royal of the Cape Observatory calculated this out from the long series of observations taken at the Observatory and deduced a sea level barometric pressure of $30{\cdot}067$ in. with a daily average variation of from $\cdot0214$ in. below that at 4 p.m. to $\cdot0243$ in. above at 10 a.m. There seems some reason to suppose that the average sea level pressure increases very slightly towards Port Elizabeth, and there can be no doubt that there is a very perceptible increase when the coast trends towards the North, as at East London and Durban. The average pressure at Durban is probably about a maximum. Beyond that latitude the known equatorial depression should begin to be felt. What we know nothing about is how far the daily variations which Mr. Stone ascertained to exist here at Cape Town can be applied to other parts of the Colony and especially to inland stations. It may be regarded as some slight argument that the daily variations are substantially the same elsewhere as they are here, that in compiling this table observations taken at different times of the day at different localities have been reduced to 8 a.m. according to Stone's table of reduction, and the result as far as it can be tested is fairly satisfactory.

The delay which has occurred in the publication of this paper in the Transactions of the Society has enabled the writer to make

certain corrections which may add somewhat to its substantial accuracy. In the course of a few years, with the experience which has been learned as to sources of error, there is a reasonable prospect that a considerable increase of accuracy may be attained in these results. Meanwhile what has been done shews that barometric observations, continued over a sufficient space of time, are capable of furnishing very useful results as to sea level. Probably however the approximate accuracy of these results is due to a great extent to the somewhat exceptional climatic conditions of the southern extremity of the African continent. There is no doubt that owing to physical circumstances there is quite an unusual degree of uniformity of average temperature over the region to which these observations apply, and it is this approximate uniformity of average temperature that renders the calculation of sea level from barometric observation as satisfactory as it seems to be. It is very doubtful whether a similar method could be applied with equally satisfactory results to such a continent, for example, as North America, where approximate uniformity of average temperature could not be assumed without leading to entirely erroneous results.

TABLE for calculating Sea Level Altitudes in feet of Places in the Cape, Colony, from average 8 a.m. barometrical readings in inches, corrected for temperature of mercury.

Bar.	Sea Level.	Differ.	Bar.	Sea Level.	Differ.
30·0	75	93	27·0	3017	103
29·9	168	93	26·9	3121	104
29·8	262	94	26·8	3225	104
29·7	356	94	26·7	3329	104
29·6	450	94	26·6	3434	105
29·5	545	95	26·5	3539	105
29·4	640	95	26·4	3645	106
29·3	735	95	26·3	3751	106
29·2	830	95	26·2	3857	106
29·1	926	96	26·1	3964	107
29·0	1022	96	26·0	4071	107
28·9	1118	96	25·9	4179	108
28·8	1215	97	25·8	4287	108
28·7	1312	97	25·7	4396	109
28·6	1409	97	25·6	4505	109
28·5	1507	98	25·5	4614	109
28·4	1605	98	25·4	4724	110
28·3	1704	99	25·3	4834	110
28·2	1803	99	25·2	4944	110
28·1	1902	99	25·1	5055	111
28·0	2002	100	25·0	5166	111
27·9	2102	100	24·9	5278	112
27·8	2202	100	24·8	5390	112
27·7	2303	101	24·7	5503	113
27·6	2404	101	24·6	5616	113
27·5	2505	101	24·5	5730	114
27·4	2607	102	24·4	5844	114
27·3	2709	102	24·3	5959	115
27·2	2811	102	24·2	6074	115
27·1	2914	103	24·1	6190	116
27·0	3017	103	24·0	6306	116

Heights calculated by the foregoing TABLE, from the average Barometric Pressure during the eleven years from 1881 to 1891 inclusive.

Station.	Average Barometric pressure.	Calculated Height.	Height otherwise determined.	Differ.	
Simon's Town ..	30·056	21	...	...	*
Cape St. Francis	30·056	21	20	+ 1	
East London ...	30·044	33	30	+ 3	* (*a*)
Royal Observatory	30·040	37	37	0	*
Cape Agulhas ...	30·009	66	55	+11	(*b*)
Mossel Bay ...	29·963	111	105	+ 6	*
Port Elizabeth ..	29·887	180	181	— 1	*
Dunbrody ...	29·851	214	200	+14	
Clanwilliam ...	29·808	254	245	+ 9	
Wynberg ...	29·811	251	250	+ 1	
Wellington ...	29·640	413	400	+13	
Swellendam ...	29·569	479	475	+ 4	
Oudtshoorn ...	28·928	1081	1063	+18	
K. Wm's. Town	28·683	1329	1314	+15	
Ceres	28·491	1516	1493	+23	
Lovedale ...	28·281	1723	1720	+ 3	
Graham's Town	28·146	1856	1851	+ 5	*
Prince Albert ..	27·887	2115	2120	— 5	
Somerset East ...	27·597	2408	2400	+ 8	
Graaff-Reinet ...	27·486	2519	2500	+19	
Stutterheim ...	27·347	2661	2700	—39	
Cradock	27·169	2845	2856	—11	*
Queen's Town ...	26·445	3597	3543	+54	
Brakfontein ...	26·117	3946	3947	— 1	
Kimberley ...	26·031	4038	4042	— 4	*
Aliwal North ...	25·762	4328	4330	— 2	*
Bloemfontein ...	25·583	4524	4518	+ 6	*
Sutherland ...	25·315	4818	4776	+42	

The results indicated by * are those which have been brought to the test by railway levelling and it will be seen that the average error is about 5 feet on either side. One source of error which the writer has not been able to eliminate is the existence in some cases of undetermined and uncorrected index error in the various instruments used. This will, it is expected, cease to affect the observations made in forthcoming years, since these index errors are now ascertained in almost all the instruments, and no doubt will in future be systematically applied.

Note *a*. For about half the period, the barometer at East London was at a 40 feet level, for the other half at 20 feet.

Note *b*. The true level of the Agulhas Barometer is in doubt, it was estimated a few years ago at 68 feet.

Subjoined is a short TABLE of Places where Observations have been made for not more than four years.

Station.	No. of years.	Average Reading.	Calculated Height.	Height otherwise obtained.	Differ.	
Sea Point ...	1	30·063	16	15	+ 1	*
Port Nolloth...	2	30·026	51	40	+ 11	*
S. A. College	4	29·976	97	115	− 18	*
Stellenbosch ...	3	29·741	318	400	− 82	
Bishop's Court	1	29·856	210	250	− 40	
Storm River ..	2	29·322	714	...	...	
Worcester ...	2	29·251	792	780	+ 12	*
Umtata ...	3	27·709	2294	2400	−106	
Beaufort West	2	27·175	2837	2850	− 13	*
Kokstad ...	2	25·169	4979	4284	+695	

Again it must be remembered that it is only in the case of those lines to which asterisks are subjoined that we have any approach to exact exterior measurement.

The only unsatisfactory line in this table is that which relates to Stellenbosch. An average barometric pressure for the three years 1889, 1890 and 1891, which were in no respect exceptional in their character, ought to have given a fairly close approximation to the true average, and a consequent fairly close estimate of the sea level. An error of over 80 feet is inexplicable, and quite contrary to the experience derived from the rest of the table. It is true that the otherwise determined sea level of 400 feet is probably an approximation by estimate only, but since the railway level is known within a mile or so of the village, it is difficult to believe that any such serious error as 80 feet can have been made. There is, however, obviously an error somewhere. The index error of −·012, which seems to have been applied in part only, will not account for this.

In the case of Kokstad there is obviously some flagrant error somewhere. How such a detailed estimate as 4,284 has been arrived at, it is difficult to say. In the years 1886 and 1887, observations were taken at Kokstad, giving an average pressure of 25·712, and a consequent sea level of 4,383 feet, differing by only 99 feet from the estimate 4,284. Our Kokstad observations are obviously at present unavailable until the source of this gross discrepancy can be ascertained.

It will be seen that a much greater apparent accuracy might have been obtained by leaving out the observations at those places where trustworthy independent means of ascertaining sea level do not exist, as also by omitting some which are vitiated by obvious errors. The real utility of the table would however have been thereby diminished, as it is very instructive to contrast those errors which may fairly be called legitimate, as they arise from the necessary imperfections of our methods, and those which are illegitimate as arising from downright blundering somewhere.